GRASSROOTS JOURNALS

Grassroots Journal of Natural Resources, Vol.7 No.3 (December 2024)
ISSN: 2581-6853 | CODEN: GJNRA9 | Published by The Grassroots Institute
Website: https://grassrootsjournals.org/gjnr | Main Indexing: Scopus and WoS

ISSN 2581-6853 | 7(3) Dec 2024

M – 00449 | Research Article

Yield and Quality of Winter Wheat (*Triticum aestivum* L., 1753) Seeds Depending on Pre-Sowing Treatment of Seed with Biological Preparations

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How to cite this paper: Konovalov, D., Polishchuk, V., Konovalova, S. and Brovdi, A. (2024). Yield and Quality of Winter Wheat (*Triticum aestivum* L., 1753) Seeds Depending on Pre-Sowing Treatment of Seed with Biological Preparations. *Grassroots Journal of Natural Resources*, 7(3): 22-38. Doi: https://doi.org/10.33002/nr2581.6853.070302

Received: 02 October 2024
Reviewed: 04 November 2024
Provisionally Accepted: 07 November 2024
Revised: 21 November 2024
Finally Accepted: 28 November 2024
Published: 30 December 2024
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Abstract

Intensive growth of the world's population, persistent climate change and food shortages are becoming major challenges of our time. For this reason, the use of intensive crop cultivation technologies to increase crop yields is a priority for the agricultural sector. The article describes the effect of pre-sowing treatment of seed with biostimulant Emistim C, micro fertiliser Avatar 1, and their combined use on the formation of yield and quality of winter wheat seeds under unstable moisture conditions. Pre-sowing treatment of seeds with biostimulant and micro fertiliser provided a significant increase in seed yield compared to the control. With the combined use of preparations for pre-sowing treatment of seed, the seed yield was significantly higher not only compared to the control but also compared to the treatment with each preparation separately. We performed a long-term study from 2018 to 2023, and obtained a similar dependence of seed yield on the pre-sowing treatment of the seed material, both separately and in combination with a biostimulant and micro fertiliser. During the study period, the seed yield was significantly higher under the pre-sowing treatment of seed with these preparations compared to the control. The highest yield of 5.8 t/ha was obtained with pre-sowing treatment in combination with a biostimulant and micro fertiliser, while in the control it was 5.1 t/ha. Pre-sowing treatment of the seed with a biostimulant or micro fertiliser had a positive effect on the yield of conditioned seeds. The yield of conditioned seeds was the highest under the combined treatment of seed with these preparations and amounted to 78%, or 6% higher than the control. It was found that pre-sowing treatment of the seed with a biostimulant and micro fertiliser significantly increased seed quality - germination energy, germination rate and weight of 1000 seeds. The obtained results of the study indicate the feasibility of pre-sowing seed treatment with a biostimulant and micro fertiliser to increase the yield and quality of winter wheat seeds, as well as the effectiveness of their combined use in growing crops under conditions of insufficient moisture.

Keywords

Germination energy; Germination rate; Biostimulant; Microfertiliser; Multiplication factor; Seed yield

Introduction

Wheat is a staple food for people around the world. Global demand for wheat is expected to grow by around 70% over the next few decades (2020-2050) as population growth and income levels sharply increase household consumption (Falcon, Naylor, and Shankar, 2022; Vitale, Adam, and Vitale, 2020). Ukraine, as one of the world's leading grain exporters, plays a significant role in providing food grain to the population, which is a strategic objective of the country's agricultural sector (Morgun and Rybalka, 2017). Winter wheat, *Triticum aestivum* (Linnaeus, L. 1753), has been and remains the leading crop in Ukraine, and there is no alternative to it (Matviichuk, Matviichuk, and Korevo, 2023). The potential of a variety is fully realised when agricultural practices are consistent with its biological properties. Research has shown that weather conditions, varietal characteristics and cultivation techniques have the most significant impact on the growth, development and yield of winter wheat (*Triticum aestivum* L.) (Linina and Ruza, 2018; Mostipan *et al.*, 2021; Skendzic *et al.*, 2023). Therefore, all agro-technological measures should be aimed at creating favourable conditions for the growth and development of crops. The use of intensive grain production technologies contributes to a significant increase in grain yields but is accompanied by significant energy consumption and environmental pollution (Kaminskiy, 2016; Lykhochvor, 2008; Nishanov and Yusupov, 2024; Skendzic *et al.*, 2023). In particular, it is known that the use of synthetic growth regulators and mineral fertilisers has a significant impact on crop productivity. However, the search for effective products and their doses for different soil and climatic conditions remains relevant. It is important to find and use the most environmentally friendly products with low toxicity and high efficiency.

Pre-sowing seed treatment with insecticides, fungicides, micronutrient fertilisers and growth stimulants is the most common and environmentally friendly way to protect plant seedlings and an important element of crop production technology (Bezpalko *et al.*, 2020; Lamichhane *et al.*, 2020). With this treatment, the seeds receive a full range of nutrition during the most important period of their germination, when the root system is formed (Afzal *et al.*, 2020; Voloshchuk *et al.*, 2020), which helps to increase the viability, germination energy and germination of seeds, the effectiveness of plant protection against pests, pathogens, resistance to drought and frost (Bilousova, Klipakova, and Keneva, 2022; Findura *et al.*, 2022). It has been found that the use of biostimulants helps to increase grain yields and quality, and has a positive effect on the crop baking qualities (Knapowski *et al.*, 2019). Increasing the intensity of seed germination and crop productivity is possible with pre-sowing preparation using growth and development stimulants and microelements (Khodanitska *et al.*, 2023; Vechera and Kuianov, 2021). More than 4.5 thousand natural and synthetic growth regulators have been studied worldwide, but they do not replace the effect of mineral fertilisers (Yavorska *et al.*, 2006). The search for highly effective and competitive stimulants in different soil and climatic zones remains a pressing issue. Growth stimulants enhance the processes of nutrition, respiration and photosynthesis, which increases fertiliser use by 20-30%, and increases the resistance of crops to adverse climatic conditions, pests and pathogens (Dyvnych and Demydenko, 2017; Shah *et al.*, 2023).

In growing high and stable yields of crops, including winter wheat, along with macronutrients, microelements are of the utmost importance in plant nutrition, the

content of which in plants and soils is quite low – 0.01-0.001% of dry matter (Hutsol, 2021), so pre-sowing treatment of seeds with Avatar 1 micro fertiliser in a gown form containing cobalt, copper, zinc, iron, manganese, molybdenum, magnesium (Polischuk and Konovalov, 2023) is an important element of the technology. The use of trace elements for pre-sowing seed treatment not only improves the quality characteristics of the seed - germination energy and germination rate - but also increases crop yields by increasing the chlorophyll content in the leaves, increasing the intensity of photosynthesis, enhancing the activity of the enzyme complex, improving plant respiration, increasing their resistance to diseases (Skendzic *et al.*, 2023; Tsyliuryk, Izhboldin, and Sologub, 2022).

The problem of increasing crop yields in the context of a steadily growing population and a shortage of food raw materials is particularly relevant and of practical importance. Therefore, the purpose of our study was to investigate the impact of winter wheat seed (grain) cultivation technology elements on the yield and quality of grain products.

Methodology

Study Area

Field and laboratory studies were conducted in the experimental farm of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine, located in the Fastiv Natural and Agricultural district of the Bug-Middle Dnipro district of the Forest-Steppe Right-Bank Province of Ukraine, during 2018-2023. The area of the experimental plot was 12 m^2 and the accounting plot was 10 m^2. The arrangement of the variants is randomised. The study used varieties selected by the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine of different maturity groups: mid-ripening - Horodnytsia, Astarta, Malynivka; medium-early ripening - Novosmuhlianka, Pochaina, Boriia. The experiment was repeated 3 times.

Pre-Sowing Seed Treatment

The scheme of the experiment provides for pre-sowing treatment of seeds with the biostimulant Emistim C (1 g/l saturated and unsaturated fatty acids (C 14 -C 28), polysaccharides, 15 amino acids, analogues of phytohormones of cytokinin and auxin nature) at a rate of 200 ml/t, microfertiliser Avatar 1 ($1\text{-}25^{-4}$% Co, $1\text{-}8^{-2}$% Cu, $1\text{-}7^{-3}$% Zn, 15^{-3}% Fe, 5^{-3} - 5^{-4} % Mn, 1^{-5} - 25^{-4}% Mo, $1\text{-}8^{-3}$ % Mg) at a rate of 1.0 l/t and joint treatment with these preparations at the same rates against the background of treatment with the fungicide Vincit Forte, 7,75%, SC (15 g/l Imazalil, 25 g/l Thiabendazole, 37.5 g/l Flutriafol). In the control, the seeds were treated only with the fungicide. Seed treatment involved wetting treatment. This method of seed treatment involves the application of suspensions, powders, and solutions with simultaneous or subsequent wetting with water. Such treatment allows to optimise the use of chemicals due to rational dosage and is safer for the health of the person involved in the treatment.

Harvest accounting was carried out by continuous threshing of plants from each plot with a Sampo-Rosenlew SR 3085 selection combined. The bunker weight of grain from each plot was converted to the yield per hectare, taking into account moisture and weeds.

The grain was cleaned from the plots and brought to seed conditions using an SM-0.15 cleaning machine. The conditioned seed yield was determined after their cleaning on a Petkus-Giant grain cleaning machine and bringing them to the requirements of the standard for sowing conditions, and the reproduction rate was determined by the ratio of cleaned seeds to sown seeds.

To determine the effect of pre-sowing seed treatment on the quality and yield of winter wheat (*Triticum aestivum* L.), seeds were treated with Avatar 1 micro fertiliser in a chelated form containing cobalt, copper, zinc, iron, manganese, molybdenum, magnesium (Polischuk and Konovalov, 2023) and plant growth regulator of natural origin Emistim C, which contains a balanced complex of natural growth substances – phytohormones of auxin, cytokinin and gibberellin nature, carbohydrates, amino acids, saturated and unsaturated fatty acids, and trace elements.

Soil and Weather Conditions

The experiments were conducted on light grey, podzolic, and light loamy soils. The topsoil had a slightly acidic reaction with the soil solution (pH 5.5-5.8), low humus content of 1.6-1.7%, alkaline hydrolysed nitrogen of 100-120 mg/kg, mobile phosphorus compounds of 90-100 mg/kg and exchangeable potassium of 70-80 mg/kg. The humus content of the soil was determined by the Tyurin method according to DSTU 4289:2004 (Soil Quality, 2005), the content of alkaline hydrolysed nitrogen was determined by the Cornfield method according to DSTU 7863:2015 (Soil Quality, 2016). Chirikov's method according to DSTU 4115-2002 (Soils, 2003) was used to determine the content of mobile forms of phosphorus and potassium. The cultivation technology included basic and pre-sowing tillage, basic fertilisation at a dose of $N_{16}P_{16}K_{16}$, sowing at the optimum time, double fertilisation with ammonium nitrate, the first at a dose of N_{51}, the second N_{34}, plant protection included a single fungicide treatment of the crop, pest control and control of monocotyledonous and dicotyledonous weeds.

Weather conditions in 2018-2023 were close to long-term averages in terms of temperature but differed in terms of precipitation. According to the figure, the vegetation periods in 2016/17, 2018/19, 2019/20 and 2021/22 were characterised by a deficit of precipitation. The amount of precipitation in the respective periods was 127.6 mm, 11.5 mm, 141.0 mm and 43.3 mm less than the long-term average, while in 2017/18, 2020/21 and 2022/23, excess precipitation was recorded with the respective values of 116.4 mm, 88.5 mm and 197 mm, respectively (Figure 1).

Statistical Analysis

Statistical processing of the experimental data was carried out by the methods of analysis of variance according to the Fisher method using the statistical analysis package STATISTICA from StatSoft (Ermantraut, Prysiazhniuk and Shevchenko, 2007; Fisher, 2006).

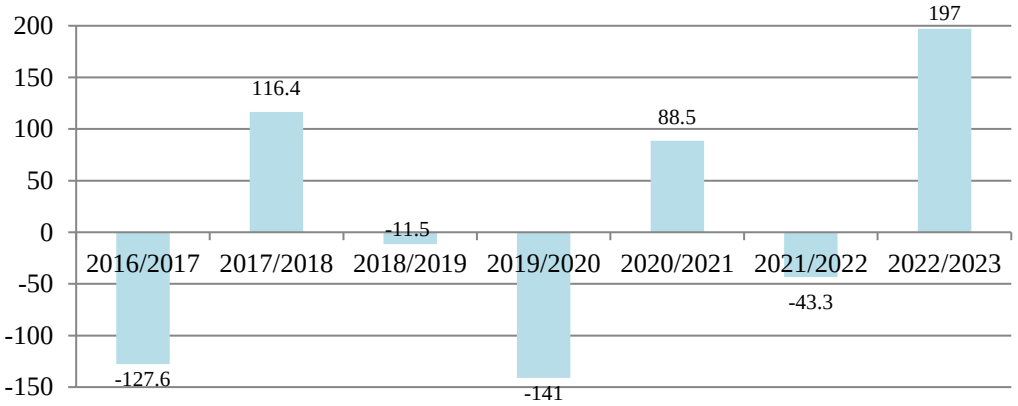

Figure 1: Deviation of precipitation from the long-term average over the years of the study (2016/17-2022/23, data from Bila Tserkva Meteorological Station (Meteorological data for Bila Tserkva, 2024)

Results

Pre-sowing treatment of seeds with a biostimulant and micro fertiliser enhanced both the crop structure and seed yield, resulting in a significant increase compared to the control. Pre-sowing treatment with the biostimulant Emistim C resulted in an average yield increase of 0.3 t/ha, while the micro fertiliser Avatar 1 led to a 0.4 t/ha increase. The highest yield gain of 0.7 t/ha (LSD05 = 0.24 t/ha) was achieved with the combined application of both treatments (Figure 2). Combined pre-sowing treatments resulted in significantly higher seed yields compared to both the control and individual treatments.

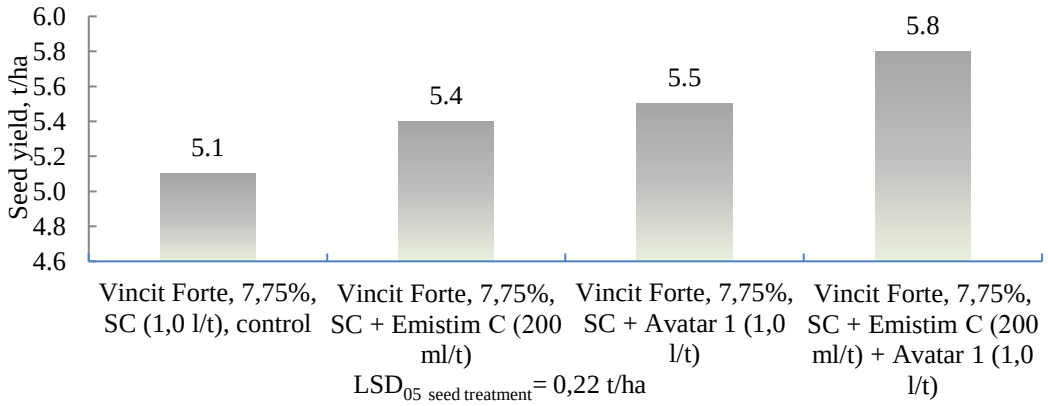

Figure 2: Seed yield depending on its pre-sowing preparation (average for 2018-2023)

Thus, under the pre-sowing treatment of the seed with the biostimulant Emistim C, the seed yield was 5.4 t/ha or 0.4 t/ha less, and under the treatment with the micro fertiliser Avatar 1 – 5.5 t/ha or 0.3 t/ha less compared to the complex treatment with these preparations. Upon analyzing the factors that influenced the yield of winter wheat based on the pre-sowing treatment of seed with biostimulant and micro fertilizer, it was found that “year conditions ” had the most significant impact, contributing 53.9%, while "seed

treatment" had a comparatively lower influence of 21.0% (Figure 3).

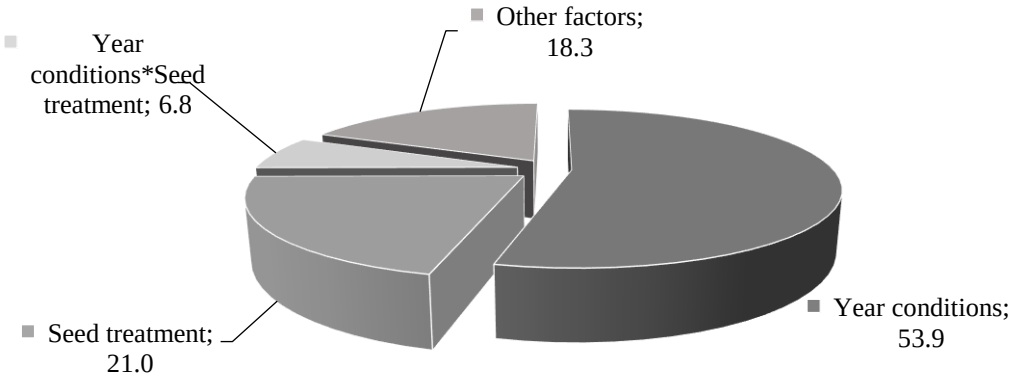

Figure 3: Influence of factors on seed yield (average for 2018-2023)

A similar dependence of seed yield was obtained depending on the pre-sowing treatment of the seed both separately and in the complex of biostimulant and micro fertiliser during the study period. Similarly, the seed yield was significantly higher in the case of pre-sowing treatment of the seed with these preparations compared to the control throughout the study. The highest yield was obtained with pre-sowing treatment in combination with a biostimulant and micro fertiliser.

Yield levels varied significantly across the study years, with the highest yields recorded in 2018 and the lowest in 2019 (Table 1).

Table 1: Seed yield depending on pre-sowing treatment and growing conditions, t/ha

Variant	*Seed yield, t/ha*				
	2018	*2019*	*2020*	*2021*	*2022*
Vincit Forte, 7.75%, SC (1.0 l/t), control	5.5	4.4	4.7	4,5	5,4
Vincit Forte, 7.75%, SC + Emistim C (200 ml/t)	5.9	4.8	5.1	4,9	6,0
Vincit Forte, 7.75%, SC + Avatar 1 (1.0 l/t)	6.0	4.9	5.2	4,9	6,4
Vincit Forte, 7.75%, SC + Emistim C (200 ml/t) + Avatar 1 (1.0 l/t)	6.2	5.2	5.7	5,3	6,5
$LSD_{05\ gen.}$	0,38				
$LSD_{05\ growing\ conditions}$	0,19				
$LSD_{05\ growing\ conditions\ seed\ treatment}$	0,22				

Thus, in the control, the seed yield in 2018 was 5.5 t/ha or 1.1 t/ha higher than in 2019 and 0.1 t/ha higher than in 2022 ($LSD_{05\ growing\ conditions}$ = 0.19 t/ha). A similar increase in seed yield was observed in the pre-sowing treatment of seed with both biostimulant and micro fertiliser in 2018 and 2022. Seed multiplication coefficients increased by 2.4 units to 22 with Emistim C and by 2.0 units to 21.6 with Avatar 1. Under the complex pre-

sowing treatment with these preparations, the multiplication coefficient was the highest and amounted to 22.8 (Figure 4).

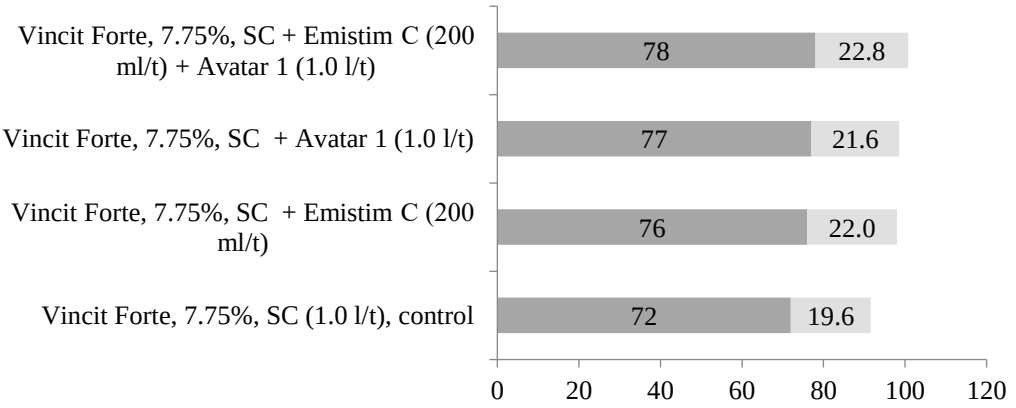

Figure 4: Reproduction rate and yield of winter wheat seeds depending on their pre-sowing treatment with biostimulant (average for 2018-2023)

Pre-sowing treatment of the seed with a biostimulant or micro fertiliser had a positive effect on the yield of conditioned seeds. The yield of conditioned seeds was the highest and amounted to 78%, or 6% higher than in the control when the seed was treated with these preparations together. An important criterion for evaluating the grown seed is the quality of seeds – germination energy and germination rate, the improvement of which is always relevant. It was found that the pre-sowing treatment of seeds with a biostimulant and micro fertiliser improved seed quality. When treated with Emistim C alone, germination energy and germination rate increased by 4% over three years and amounted to 92% and 94%, respectively, and the weight of 1000 seeds increased by 2.7 g and amounted to 44.6 g compared to the control (Table 2).

Table 2: Quality of winter wheat seeds depending on biostimulants pre-sowing seed treatment (average for 2018-2023)

Variant	*Weight of 1000 seeds*		*Germination energy*		*Germination rate*	
	g	*±, g*	*%*	*±, %*	*%*	*±, %*
Vincit Forte, 7.75%, SC (1.0 l/t), control	41.9	-	88	-	90	-
Vincit Forte, 7.75%, SC + Emistim C (200 ml/t)	44.6	2.7	92	4	94	4
Vincit Forte, 7.75%, SC + Avatar 1 (1.0 l/t)	44.3	2.4	93	5	95	5
Vincit Forte, 7.75%, SC + Emistim C (200 ml/t) + Avatar 1 (1.0 l/t)	45.5	3.6	95	7	96	6
LSD_{05}	0.3	-	1.1		1.1	-

A similar dependence was observed in the pre-sowing treatment of seeds with Avatar 1 micro fertiliser: germination energy and germination rate were 5% higher compared to the control. It is worth noting that no significant difference in seed quality was found

depending on its treatment with a biostimulant or micro fertiliser. The combined pre-sowing use of the biostimulant and micro fertiliser produced significantly higher seed quality indicators compared to the control. On average, over three years, the germination energy increased by 7% and amounted to 95%, the germination rate by 6% and amounted to 96% (LSD_{05} = 1.1%), and the weight of 1000 seeds increased by 3.6 g and amounted to 45.5 g (LSD_{05} = 0.3 g). The same results were obtained for the years of research. Seed germination was significantly higher in the pre-sowing treatment of seed material compared to the control for all years of research (Figure 5).

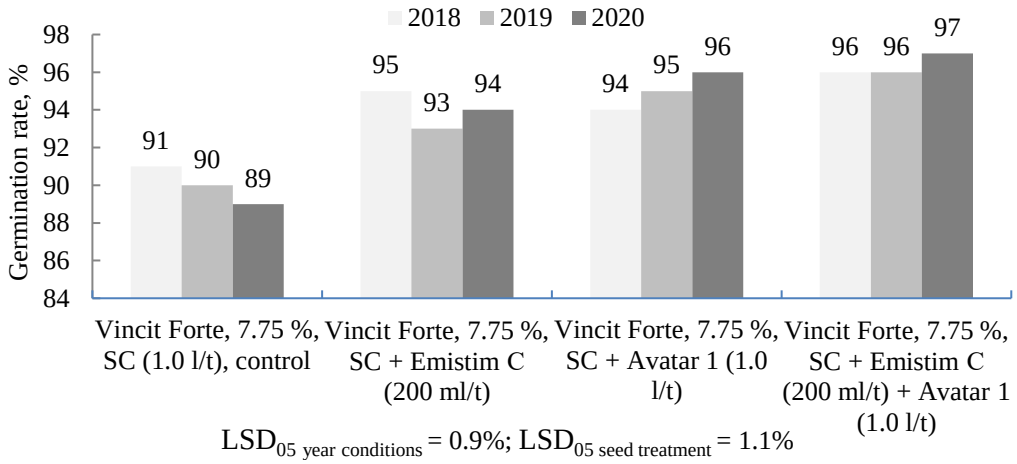

Figure 5: Seed germination depending on seed treatment by biostimulant (for 2018-2020)

In 2018, pre-sowing treatment with Emistim C increased seed germination to 95%, compared to 91% in the control. A similar increase in seed germination was observed when the seed was treated with Avatar 1 micro fertiliser. When combined use of a biostimulant and micro fertiliser, the highest seed germination rates were obtained, which by years was 96-97%, while in the control it was significantly lower.

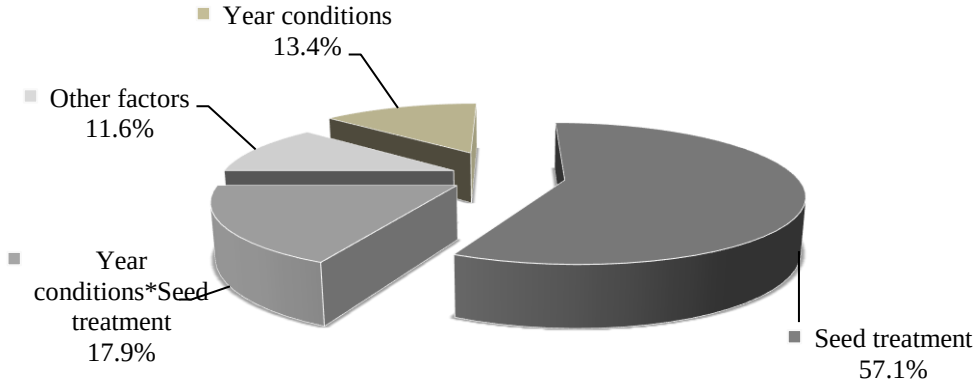

Figure 6: Influence of factors on seed germination (average for 2018-2023)

Analysis of the factors that influenced seed germination showed that the factor "seed treatment" was the most influential (57.1%). The influence of the complex interaction of the factors "seed treatment" and "year conditions" was 17.9%, and the factor "year conditions" – was 13.4% (Figure 6).

Pre-sowing treatment of seed with biostimulant Emistim C and micro fertiliser Avatar 1 for all years of research provided a significant increase in the weight of 1000 seeds, both when treated separately with one of these preparations and when used together, compared to the control (Figure 7).

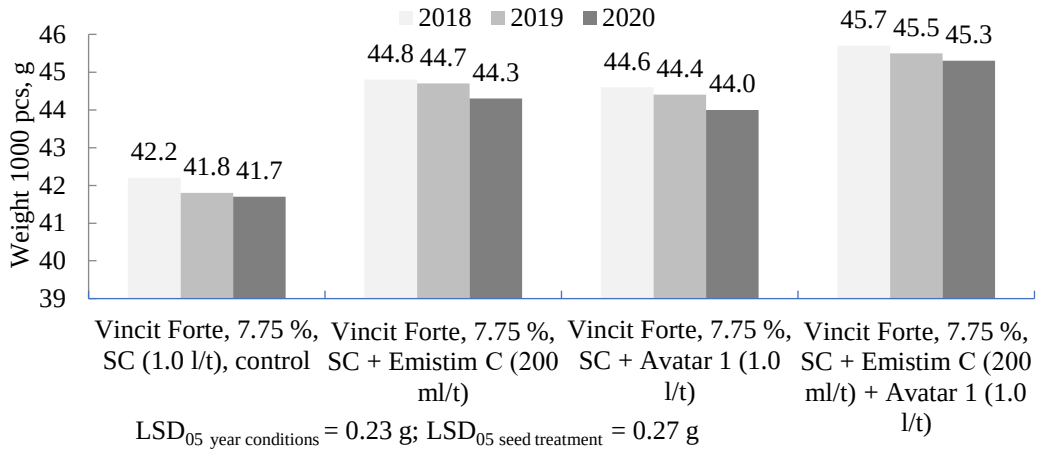

Figure 7: Weight of 1000 seeds depending on the treatment of the seed with biostimulant (2018-2020)

Thus, in 2018, the weight of 1000 seeds was 2.6 g higher under the pre-sowing treatment of seed with the biostimulant Emistim C, 2.4 g higher under the micro fertiliser Avatar 1, and 3.5 g higher under their combined use compared to the control (LSD_{05} = 0.27 g). A similar increase in the weight of 1000 seeds was observed in 2019 and 2020. The combined use of these preparations provided an increase in the weight of 1000 seeds not only compared to the control but also when treated separately with one of these preparations. If in 2018 the weight of 1000 seeds under the treatment of seed with a biostimulant was 44.8 g and micro fertiliser 44.6 g, then under their combined use it significantly increased by 0.9 g and 1.1 g (LSD_{05} = 0.27 g). A significant increase in the weight of 1000 seeds under the combined pre-sowing treatment of seed was obtained in 2019 and 2020. Thus, the pre-sowing treatment of seed with the biostimulant Emistim C and micro fertiliser Avatar 1, both separately by each of the preparations and in combination, provided a reliable increase in the yield of seeds and their quality.

Discussion

It is known that the intensification of agriculture threatens the development of natural ecosystems and can lead to environmental losses. The use of fertilisers increases plant productivity, but it also increases economic costs and puts an additional burden on the environment (Garcia, 2020). Today, the criterion for agricultural production is not only to increase production but also to preserve the natural and ecological balance of the environment (Voronkova *et al.*, 2019).

The search for alternative sources of plant nutrients is an urgent issue for the science and practice of crop production (Ashraf and Foolad, 2005; Vozhehova *et al.*, 2021). To increase the yield potential of crops, growth stimulants are used to activate membrane processes, cell division, photosynthesis, reduce nitrate content in plants, increase the biological efficiency of crop production, and resistance to diseases and pests (Bahan and Nevodnychyi, 2023). The combined use of herbicides and biostimulants reduces the negative effects of herbicides. The use of physiologically active substances, in particular, sodium humate and gimisol, contributes to an increase in yield compared to the control without their use (Nepran, Romanova and Romanov, 2021). Covering a wide range of substances, including natural compounds and products of microorganisms, biostimulants stimulate the development of the root system of plants, contribute to increasing their resistance to the negative impact of biotic and abiotic factors, in particular, increase their environmental plasticity and resistance to diseases and pests (Baratova and Yunusov, 2023).), however, their use involves additional economic costs, which necessitates the study of the economic and social effect of their use.

A significant number of scientific studies have been devoted to exploring the effectiveness of biostimulants in growing crops. It was found that foliar feeding of plants with micro fertiliser and biostimulant growth promotes a 28.2% increase in buckwheat grain yield compared to the control (Moisiienko, Tymoshchuk and Panchyshyn, 2023).

When studying the reaction of spring wheat to the introduction of biostimulants containing microorganisms, Piskier (2006) found a significant increase in the yield of spring wheat grain by 23%. Matyjaszczyk (2015) recorded an 8% increase in the productivity of soft wheat when using a biostimulant that includes growth hormones, amino acids and enzymes of biological origin. Radzikowska-Kujawska *et al.* (2023) have confirmed that the use of any biostimulant significantly increases grain yields under conditions of full hydration. They recorded the highest yields when applying the Raiza-Mix preparation, which is based on algae, amino acids, growth hormones and trace elements. Thus, there is a need for an in-depth study of various biostimulants on crop yields. Yula and Drozd (2021) determined that, on average, over the years of research, the increase in the yield of spring wheat with the use of growth biostimulants ranged from 0.2-0.35 t/ha. Relevant studies were conducted in different soil and climatic conditions under different crop cultivation technologies, which could affect the results of the study, for which reason there is a need for an in-depth study of the effect of biostimulants on crop yields, taking into account the effects of climatic factors and elements of winter wheat cultivation technology, which would allow selecting the most effective ones.

In the zone of sufficient moisture, treatment of winter wheat seeds with biological preparations Emistim C and Rizoplan provided an increase in seed yield by 10.4-17.2% compared to the control without treatment with these preparations (Voloshchuk, 2009). Hanhur *et al.* (2021) have shown that seed treatment and foliar feeding of winter wheat crops with micro-fertilisers had a positive impact on crop productivity. Thus, the increase in wheat grain yield from a seed treatment with Vuksal Terios-U and Vuksal Terios-M micro fertilisers compared to the control (untreated seeds) was 0.18-0.19 t/ha or 3.5-3.7%. Lykhochvor *et al.* (2022) have determined that the yield of winter wheat increased by 8% after applying Intermag micro fertiliser.

Our research indicates that it is advisable to use a biostimulant and microfertiliser in combination. According to our study conducted in the conditions of insufficient moisture in the Right-Bank Forest-Steppe of Ukraine, the use of biostimulants Emistim C and Avatar 1 increased the yield of winter wheat seeds by 0.3-0.7 t/ha, i.e. by 5.9-13.7%, compared to the control. Thus, the results presented in this article agree with the results obtained by researchers under different growing conditions and indicate the expediency of using biostimulants to increase crop yields. Given that the profitability of production for growing winter wheat seeds using energy-saturated technology with elements of colonisation was lower compared to energy technology, the search for alternative environmentally friendly ways to increase crop productivity is important and determines further research directions.

Studies of the influence of factors on the yield of winter wheat under moderate moisture conditions of the Left-Bank Forest-Steppe of Ukraine have determined that under the appropriate growing conditions the influence of weather conditions on the formation of yields ranged from 10.5-11.1%, depending on the variety (Barabolia and Doronin, 2023), while the influence of this factor in the Steppe of Ukraine increased to 61.1% (Klipakova *et al.*, 2018). In our research, the influence of this factor was 53.9%, which indicates an increase in the share of this factor in conditions of moisture deficit. The influence of the factor 'seed treatment with disinfectants and plant growth regulators' in the steppe conditions was 36.2% and 2.1%, respectively (Klipakova *et al.*, 2018), and the share of the factor 'treatment with biological products' was 9.34% (Bazalii and Domaratskyi, 2012). The share of the influence of the factor 'seed treatment' in our research was 21%, which is significantly different from the results of previous studies and determines the need for further research on the effect of seed treatment with various preparations on the yield and quality of winter wheat seeds under different growing conditions.

Conclusion

The persistent challenges of rising population pressures and the impacts of climate change necessitate the exploration of alternative methods to enhance crop yields. Consequently, this research aims to examine the influence of different elements of winter wheat seed-growing technology on both the yield and quality of grain products. It was found that pre-sowing treatment of seed with biostimulant Emistim C, seed yield increased by 0.3 t/ha, with micro fertiliser Avatar 1 – by 0.4 t/ha, and under the complex application of these preparations - by 0.7 t/ha (LSD_{05} = 0.22 t/ha), compared to the control. Under pre-sowing treatment of seed with biostimulant Emistim C, the seed multiplication coefficient was 2.4 units higher, with micro fertiliser Avatar 1 – 2.0 units higher, and under combined use of these preparations – 3.2 units higher compared to the control. Pre-sowing treatment of the seed with a biostimulant and micro fertiliser had a positive effect on the yield of conditioned seeds. Under the combined treatment of seed with these preparations, the yield of conditioned seeds was the highest and amounted to 78%, or 6% higher than in the control. It was determined that the pre-sowing treatment of seeds with biostimulant and micro fertiliser significantly improved seed quality compared to the control. On average, over three years, when treated with Emistim C alone, germination energy and germination rate increased by 4% and amounted to 92 and 94%, respectively, and the weight of 1000 seeds by 2.7 g and amounted to 44.6 g, compared to the control. The combined use of the biostimulant and micro fertiliser

increased germination energy by 7%, germination rate by 6%, and weight of 1000 seeds by 3.6 g. The obtained results indicate the effectiveness of the combined use of biostimulant and micro fertiliser in the Right-Bank Forest-Steppe of Ukraine and necessitate further search for environmentally safe and highly efficient ways of growing crops in different growing conditions.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	Yes	No
Collected the data	Yes	No	No	No
Contributed to data analysis & interpretation	Yes	No	No	No
Wrote the article/paper	Yes	Yes	No	Yes
Critical revision of the article/paper	Yes	Yes	Yes	No
Editing of the article/paper	Yes	No	No	Yes
Supervision	No	Yes	Yes	Yes
Project Administration	Yes	No	No	Yes
Funding Acquisition	Yes	No	Yes	No
Overall Contribution Proportion (%)	35	25	20	20

Funding
No financial support was received for the research and writing of this article.

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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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